



Manufacturing Impact: Training the Trainers

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Prior to Texas A&M, she was a Master Teacher in Spring Branch Independent School District for 26 years and a Department Chair for Memorial High School in Houston, Texas. Always interested in unleashing the imagination of students, she incorporated 3D printing in her classroom for 18 years, and was awarded the PTA District School Bell Award for her service in STEM Education.

She has been a leader in engineering education in the state of Texas throughout her career. Projects include creating and leading new teacher boot camps, developing the Texas standards for the Math/Physical Science/Engineering teacher certification and most recently developing the Texas Essential Knowledge and Skills frameworks in STEM education. Widely known for her work with Project Lead The Way (PLTW), she served as the State Lead Master Teacher training over 700 teachers in PLTW Core Training Institutes for 13 years.

Shelly holds a B.S. degree in Industrial Design and Development and a M.Ed. in Teacher Leadership. She believes in empowering teachers, who then empower students to go out and change our world.

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Abstract

This paper presents the synergetic effort to increase manufacturing related activities and interests among middle school and high school students. Funding from National Science Foundation (NSF) was awarded to train 36 teachers who are currently involved with robotics, pre-engineering, or technical programs. The in-service teachers are selected from minority serving Independent School Districts (ISDs) in Texas, while the pre-service teachers are from Science Technology Engineering and Mathematics (STEM) education programs at different universities. Additional funding that matches NSF stipend to additional teachers was also provided by industry and Gene Haas Foundation. The industrial partners also contributed with complimentary professional training and free computer-aided drafting and manufacturing (CAD/CAM) software to participating teachers and their schools.

The program trained 29 teachers in the previous two summers. The teachers published their lesson plans and implemented in their classes with the new activities and knowledge that they have acquired during the training. Some teachers participated in a regional conference, guided and brought their students to different competitions, and won numerous awards including the first prize in robotics competition at the state level. Issues from the first summer was learnt and rectified; the program in the second summer simplified research activities, implemented a design and manufacturing project while having frequent feedback and assessment sessions using clicker.

I. Introduction

The state of Texas enjoys its manufacturing output of \$232.2 billions or 15.2% gross state product in 2014, yet Texas has only 7.6% of its workforce in manufacturing [1,2]. Figure 1 shows the manufacturing growth in Texas, in terms of real Gross Domestic Product (inflation-adjusted GDP) is almost double that figure of the whole USA [3]. The growth rate for real GDP in Texas has been approximately 57% since 2009 (Fig. 1), but the numbers of manufacturing employment has been fluctuating in the range $\pm 6\%$ (Fig. 2). The robust contribution has been due to the fast growth of skilled labors in advanced manufacturing and the reduction of unskilled labor. To maintain and enhance the healthy trend of GDP contribution from manufacturing, the growth of highly skilled workforce in manufacturing must be improved. However, advanced manufacturing development is facing serious issues due to lack of student interest. Figure 3 shows the demographics of selected independent school districts (ISD) in Texas. The ISDs of Bryan, Navasota, Brenham, and Pharr-San Juan-Alamo (PSJA) have about two times more African American or Hispanic students than the average ISD in Texas. The number of students from low-income families is also 20-50% more than the state average. The dropout rates at Bryan and Aldine ISDs are also particularly alarming.

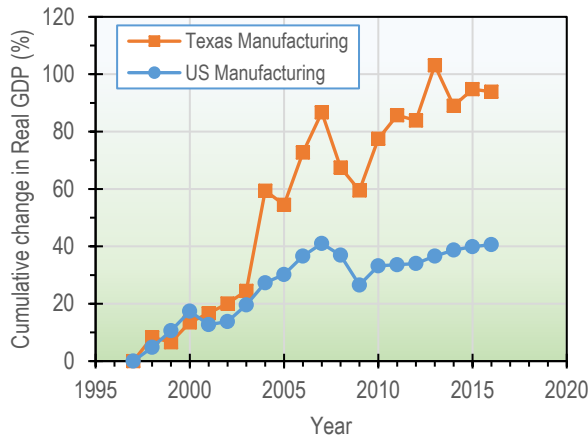


Fig. 1: Contribution of manufacturing to gross domestic product in Texas and the USA [3].

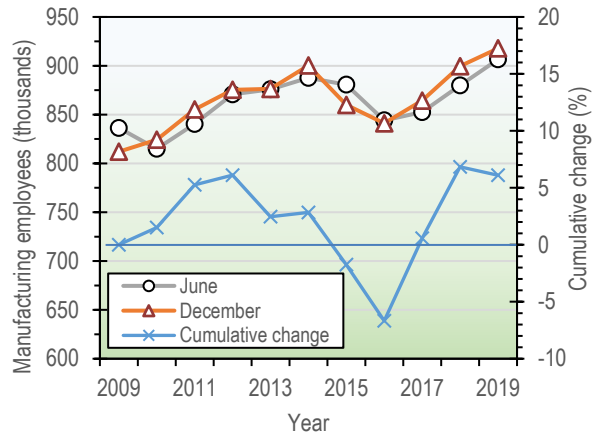


Fig. 2: Manufacturing employment in Texas [4].

Research studies have identified issues with K-12 classes in efforts to promote STEM and manufacturing. Dailey *et al.* [5] concluded that quality of teaching in K-12 classes could be compromised and affecting the students' academic achievement since:

- 69% of grade 5-8 students were taught by mathematic teachers who were not mathematic certified or did not have a formal mathematic training.
- 93% of middle school had the same issues in physical science classes.
- At high school level the issues were 31% for mathematics, 61% for chemistry, and 67% for physics.

Teachers, having yet to teach project-based classes, give different opinions when advising students, concluded Nathan *et al.* [7] in their research study. Those who involved with Project Lead The Way Program (PLTW) believed that mathematics and science content should be integrated in engineering project activities to benefit students; however, the non-PLTW teachers believed that a high scholastic achievement is the prerequisite for engineering career.

In a survey of 520 participants, Yang *et al.* [8] found that:

- 40% of participants believed that K-8 STEM education was inadequate, and professional development was insufficient.
- 38% of participants felt that their curricula only include introduction to engineering and technology.

The authors then recommended (i) organizing training and providing professional development for teachers, and (ii) establishing close partnership among universities, colleges and local ISDs.

Other educators have agreed that not only additional training to in-service teachers is needed, but also recommending further training to pre-service teachers. Bracy *et al.* [6] concluded that additional training to pre-service teachers would significantly increase their self-efficacy in STEM teaching, their own interest /attitudes toward science, and their understanding of inquiry-based STEM instruction. Similar findings were reported by other educators [5, 8, 9].

School programs with hands-on and manufacturing focuses –as compared to academic mathematics or pure science– would be attractive to students since they can relate the training to everyday examples, potential employment, and even advanced careers. Some middle /high schools, however, limit the growth of their technology-related programs, robotics clubs, or SkillsUSA programs due to budget constraints and/or lack of technical expertise of teachers. It

would be necessary to reverse the trend by providing infrastructure and manufacturing expertise to teachers so that young students are inspired to join technology programs and consider technology or engineering as their primary choice.

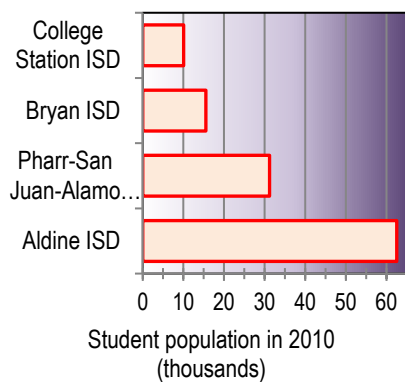


Fig. 3: Student population at targeted Texas ISDs [4,5].

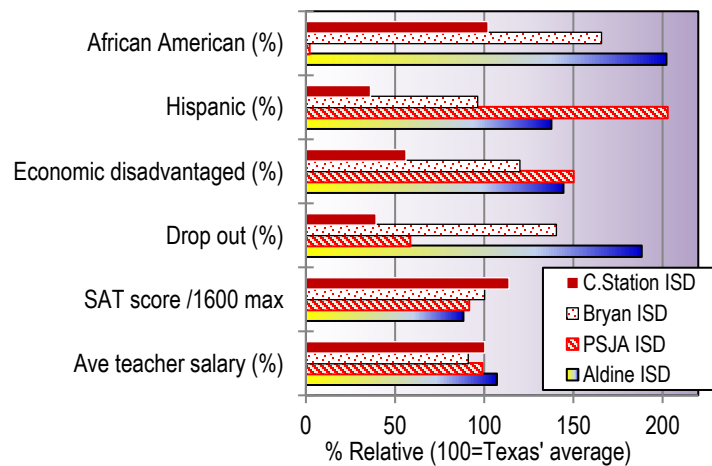


Fig. 4: Demographics of targeted ISDs [4,5].

The manufacturing focused Research Experience for Teachers (RET) site at Texas A&M University (TAMU) provides manufacturing experiences to teachers from middle and high schools with large numbers of students from underrepresented groups and averaged academic achievement. The program objectives are to:

- Enhance the teachers' professional knowledge by providing unique research experiences in modern and advanced manufacturing,
- Use a design thinking approach to help teachers integrating new research knowledge into their class /laboratory activities while motivating young students to pursue engineering careers,
- Support the school infrastructure for long term partnership, and
- Enhance the schools' quality and performance for continuous collaboration with the host university.

This paper presents the program structures of the last two summers 2018-2019, feedback from participants, and the impact on students at participating schools.

II. Program Details

National Science Foundation (NSF) supports our three-year program that involves a total of 36 teachers and focuses on three main aspects of manufacturing: metrology, materials, and fabricating processes. The six-week summer research program comprises of an orientation and informative discussion on laboratory safety, research methodology, design methodology, hands-on research activities with graduate and undergraduate students, seminars, and facility tours to local companies, different departments, and research centers. Such program would strengthen collegial relationship, enhance the participants' professional knowledge so they could integrate new and appropriate material into secondary school curriculum, and implement the gained knowledge into their classroom and/or laboratory activities. The targeted ISDs are either with

high needs in rural areas or serving a significant number of students from underrepresented groups. Pre- and post-program surveys gauge the gained knowledge of the participating teachers while formative and summative interviews by a qualified external evaluator confirm if the objectives are met.

Additional funding support from industry and Gene Haas Foundation allows additional teachers to participate in this program. One additional teacher was recruited in summer 2018, and three more teachers will participate in the coming summer without significant effects on the faculty mentors and their student assistants.

A small group of in-service and pre-service teachers will work closely with RET faculty mentors and his/her students on a specific research project for six weeks in summer. An orientation to review safety, research methodology, ethics, and be familiar with research facilities will smooth the transition of participants to the program. Information on the program website allows the selected participants to know their research team and project information before the program start date. This provides an opportunity for them to contact the research team to clarify the research objectives and scope so that the participants could (i) do preliminary investigation and be well prepared before joining the program and (ii) possibly bring complementary materials from their schools to complement the project. The PK-12 Engineering Education Outreach Office at TAMU also provides logistic helps with parking permit, renting university accommodation for the summer. Pre- and post-program surveys are integrated in the program. In addition to working closely with students and RET faculty team on a specific research project, all teachers in this program will meet teachers from other on-campus programs for seminar, and/or tour local companies or laboratory facilities at different departments. This provides opportunities for cross communication and interaction among all mentors and participants.

Design thinking and team-approach would be applied in research training to foster collegial relationship. After assigning a project during the first week, each team of 2-3 teachers applies the design methodology to come up with an optimal solution. Each team then selects materials, fabricates components to solve the problem at the end of 5th week. Results are shared among teachers from this and other RET programs on campus.

All teachers will spend five weeks working on specific projects; they will spend the last week to integrate research experiences into his/her laboratory or classroom activities with help from the Outreach officers. One or two teachers – one in-service and one pre-service teacher -- would be selected to present his/her research work at the annual STEM-4-Innovation Conference hosted by TAMU in College Station in February. They will share their experiences and research outcomes with other teachers from other states attending the conference.

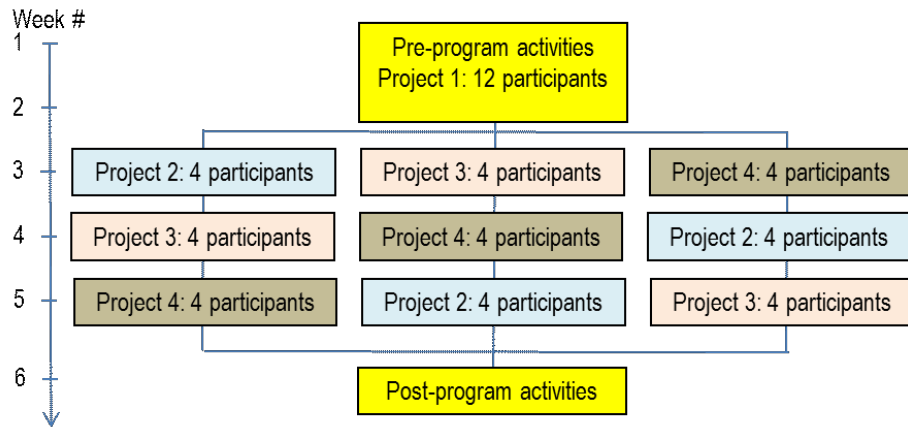
The teachers will start with traditional manufacturing (Project 1) that form a base for subsequent projects, while providing transitional and levelling steps to the pre-service teachers. Groups of two teachers will work on different machines and then rotate to cover all aspects of manufacturing: metrology, material, and fabrication using manual machines before practicing on computer-controlled machines. Upon completion of Project 1, the teachers will then work in smaller groups with graduate students on more advanced subjects (Projects 2-4). All projects are listed below and on the program website with more details such as objectives, expected outcomes, and contact information of respective mentors. These topics, carefully chosen from suggested topics from industry and experienced teachers, are relevant to participants who teach technology or mentor students in robotics, SkillsUSA, machine shop, design, computer-aided graphics, or computer-aided design toward the required endorsement according to Texas

Essential Knowledge & Skills (TEKS) and Texas Science, Technology, Engineering, and Mathematics (T-STEM) initiatives.

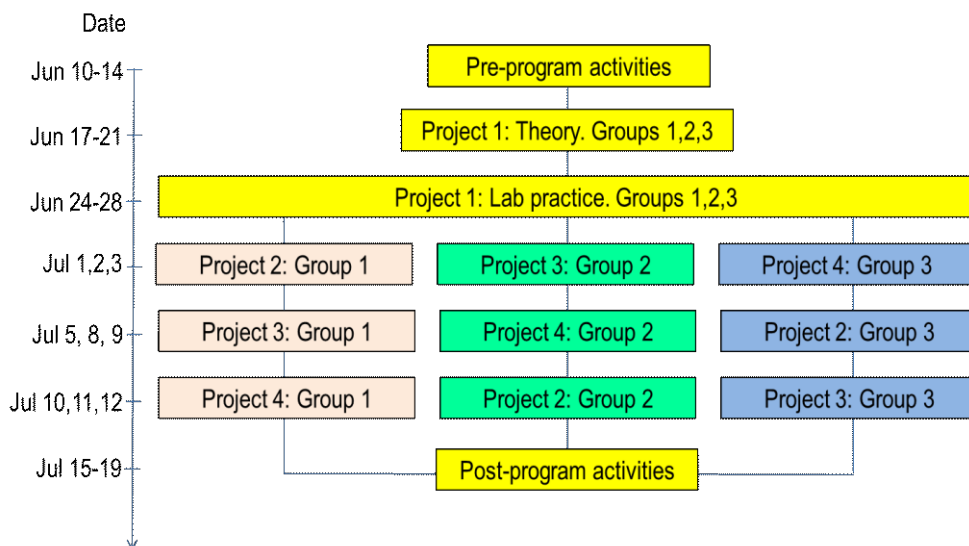
Based on the participants' feedback and suggestion from the external evaluator in summer 2018, the program for 2019 was modified so that the content and new knowledge can be easily implemented to middle/high school level. The revised program with more hands-on activities and team participation had received very positive comments from both participants and the external evaluator. Table 1 and Fig. 5 compare and contrast the two programs.

Table 1: Comparison of program schedules and projects.

Project #	2018-Program		Topic	Duration
	Topic	Duration		
1	Metrology, machining	2 weeks	Metrology, machining, stamping	3 weeks
2	Additive manufacturing	1 week	Laser machining	3 days
3	Material-manufacturing relationship	1 week	Additive manufacturing	3 days
4	Surface engineering	1 week	Surface engineering	3 days
5	No comprehensive project		Comprehensive project	1 week



(a) Summer 2018



(b) Summer 2019

Fig. 5: Comparison of structure and timeline of 2018-2019 programs.

Project #1: Traditional Manufacturing.

- Participants: 12-15 teachers
- Focus: material, metrology, and traditional processes
- Lab Training:
 - Traditional machining uses a hard cutting tool to remove softer materials as chips. A part must be clamped rigidly to withstand a high cutting force while minimize vibration. Participants will learn the safety rules, basic metrology, machining principles, then practice with manual saw, mill, drill, lathe, and grinder to produce and assemble a set of parts within tolerances. In the second week, the participants will be introduced to computer aided drafting (CAD) and computer aided manufacturing (CAM). The teachers will learn using Fusion360 software that will be complimentary to their schools. They will design the same pen and pen-base set using the CAD module, then generate the corresponding codes to fabricate the pen and pen-base set again using computer numerical controlled (CNC) lathe and milling machines.
 - Stamping process transforms metal sheets into useful shapes. Participants will have hands-on experiences with shearing, bending, punching, cup drawing, and resistance welding to produce a 3D star.
- Authentic research experience: Participating teachers will gain basic manufacturing skills before completing advanced manufacturing projects.
- Equipment: Fabrication: manual brake, cup drawing, resistance welder, lathe, saw, drill, mill, CNC lathe, CNC mill, computer- integrated manufacturing facility. Metrology: caliper, micrometer, height gage, go/no-go gage, measuring microscope, surface profilometer, optical profile projector.
- Schedule and activities: One week with manual machines, and one week with CNC machines. A pair of teachers will work on one machine/task then rotate to others. The faculty mentors will spend one hour/day with the participants, and six students will work with six teacher pairs to finish the tasks.
- Expected outcomes: Experience with metrology techniques using basic hand tools and sorting technique. Know the safety rules in laboratory, and principle of machining and stamping operations. Obtain hands-on experience with manual and automatic machines. Know the effect of machining parameters on part quality and processing rates to guide their students at home institution to choose appropriate materials and optimal machining parameters.



Fig. 6: Fabrication of a pen base and pen holder by traditional machining.



Fig. 7: Fabrication of a 3D metal star by stamping and welding.

Project #2: Laser Processing.

- Participants: 4-5 teachers
- Focus: 3-day education/research experience on fundamentals of laser cutting/engraving, and on-site training on programming for laser processing, its operation, and post-fabrication finishing.
- Lab Training and Integrated Project: This exercise will afford teachers the ability to fabricate 2-D geometries through laser processing (cutting/engraving) on a variety of materials by creating models, selecting the proper process parameters, operating the laser, and post-processing.
- Authentic Research Experience: Participants will gain a deep understanding of laser operational parameter effects and tolerances on different types of materials, as well as effective programming and operation of the laser cutter/engraver; such knowledge/skills will be employed to fabricate a component of the Stirling Engine.
- Equipment: Laser cutter/engraver, Laser processing software, Finishing tools
- Expected Outcomes:
 - Be able to create 2-D models for processing by the laser cutter software
 - Be able to select appropriate process parameters for the laser cutter based on the material type/thickness
 - Be able to effectively and safely operate the laser cutter/engraver
 - Ability to communicate technical course knowledge/concepts to a wide audience
 - Create a first draft curriculum module that utilizes laser cutting/engraving

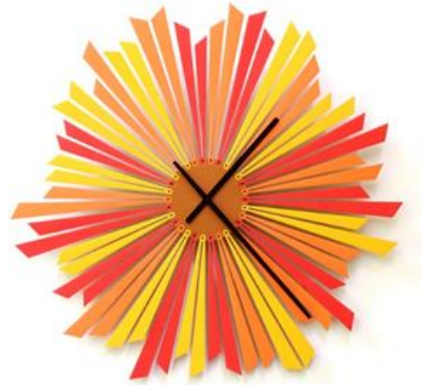


Fig. 8: Laser-cut clock made from birch and hand painted

Project #3: Additive Manufacturing

- Participants: 4-5 teachers
- Focus: 3-day training on fundamentals of additive manufacturing and hands-on training on selected technologies, including model generation, preparation, pre- and post-processes.
- Lab training and integrated project: This short course aims to empower teacher ability to identify and select proper additive method and post-processing techniques by considering part complexity, surface finish and tolerances, production time and costs. Participants will learn and experience two 3D printing technologies (*Fused deposition modeling* (FDM) and *Stereolithography* (SLA)) and compare them to the traditional polymer casting technique.



Fig. 9. Additively manufactured parts by SLA (left) and FDM (right)

Participants will use a 3D scanner to produce a digital model, convert to STL file, and perform model slicing. They will learn how to properly orient the part considering the part strength, appearance, and the removal of support structures. They will use different post processes to finish the part, including chemical vapor polishing (for FDM) and post-UV curing (SLA). In parallel, they will learn polymer casting using a flexible silicone mold. All finished parts will then be compared quantitatively by i) surface finish, ii) dimensional accuracy, and iii) total production time.

- Authentic research experience: Participants will gain necessary additive manufacturing skills, understand the pros and cons of different additive manufacturing methods in a quantitative manner.
- Equipment:
 - Fabrication: FDM printers (Dreameer and TAZ mini), SLA printer (Form 2), UV-curing station, fume hood, iso-thermal oven, vacuum chamber.
 - Metrology: Calipers, CMM, surface profilometer, white light interferometry, digital microscope.
- Expected outcomes: At the end of this training, the participants should:
 - Be able to identify and describe various 3D printing technologies.
 - Know basic 3D printer operations and post-processes.
 - Understand the effects of model slicing and part orientation.
 - Have the first draft of curriculum integration

Project #4: Surface engineering.

- Participants: 4-5 teachers
- Focus: a 3-day experience on fundamentals of surface engineering, surface characterizations and related approaches for data analysis
- Lab training and integrated project:
 - Achieve fine finished surfaces for metallic material samples,
 - Obtain hands-on experience on operating precision device for surface quality characterizations,
 - Understand basic approach for evaluating surface quality/integrity, and
 - Have basic understanding of the quality engineering and statistical process control tools.
- Authentic research experience: Participants will gain knowledge of the surface engineering, interchangeability, quality engineering and hands-on experience of operating surface measurement equipment.
- Equipment: Surface profiler, Interference microscopic profiler, Hardness test machine (indenter) and other machines (optional) for advanced surface analysis and characterizations
- Expected outcomes:
 - Understand basic concepts related to surface engineering
 - Understand knowledge and experience in analytic approaches for analysis of surface integrity and statistical process control
 - Experienced with metrology and surface characterization/imaging equipment

III. Participant Selection

Table 2 lists the targeted independent school districts with great potential for success. The targeted institutions offer pre-engineering, technology, and science programs that are closely related to the research focus of this proposal. The Bryan ISD and Aldine ISD are serving many African American and Latino students in their school districts.

Table 2: List of targeted school districts.

Independent school district (ISD)	Website	Location in Texas	Note
College Station ISD	www.csisd.org	College Station	Near TAMU
Bryan ISD	www.bryanisd.org	Bryan	Near TAMU, high African American population
Aldine ISD	www.aldineisd.org	Houston	High African American population
Pharr/San Juan/Alamo ISD	www.psjaisd.us	Pharr	High Hispanic American population

IV. Follow-up Plan

The Outreach Office and RET faculty team worked with participating teachers especially during the first and last weeks of the summer program to come up with a sustainable follow up plan. Raise Achievement LLC, the external evaluator, collaborated with the Outreach Office to assess the following steps:

- Implementing plan. A pair of teachers from the same school completes an assignment that describes the gained knowledge and how to implement it to classroom lessons or projects. The pre-service teachers may join the in-service teacher in this planning stage. After having a specific plan, the team identifies issues such as lack of resources and proposes how to use the \$1,600/teacher toward implementation.
- Sharing facilities. The team comes up with plan to bring students back to TAMU for engineering lab tours, workshops, and possibly share facilities at TAMU to complement school assignments or competition projects. Such work is supported by the graduate students who work with the teachers during the summer research program.
- Developing long-term relationship. Meetings for following academic year among RET project team members, teachers, school district officers, and industry representatives are planned to assess the success of implementing plan, its schedule, impact on students and parents, and to generate ideas for broader impact.
- Sharing experiences. Two teachers (one in-service and one pre-service teacher) are invited to participate and present their research experiences at the annual STEM-4-Innovation Conference in Texas. The in-service teachers also present how they integrate new knowledge gained from the research experience into their lessons, laboratory or school projects and the impact on students.



Fig. 10: Activities of teacher participants

V. Discussions

The intensive manufacturing training for 12 teachers was completed in summer 2018, and another 13 teachers in summer 2019. Typical activities are shown in Fig. 10 a-h. The participant demographics in the last two summers includes:

- Twenty in-service and five pre-service teachers
- 100% STEM major
- Nine females (36%)
- Fourteen African /Latino participants (56%)
- All the in-service teachers are from ISDs with very high number of under-represented groups.

Hands-on laboratory practices using appropriate machines /instruments and complementary theories were provided to the participants. Feedbacks from the 2018-summer participants included:

- a) Having more times for hands-on activities on basic manufacturing while shortening the high-level research activities.
- b) Missing link among different projects.
- c) Lacking mechanism to gage newly gained knowledge of participants.

The following changes were made to the 2019 program.

- a) Longer practice time. Two-week leveling training was provided during summer 2018, but three-week training was provided for summer 2019 (Table 1 and Fig. 5). The basic training was necessary for all teachers before attending the more focused and relevant topics in smaller groups with graduate students.
- b) Comprehensive project. A project would be assigned during the 1st week and be completed before the 6th week. A team of two or three teachers will apply design methodology to come up with their optimal solution, and then use their new skills to manufacture components to enhance an existing design –an inexpensive Stirling engine that can be implemented at their schools. The project serves as an integrating exercise that combines the necessary hard skills in manufacturing (i.e., technical drawing, material selection, manufacturing process, and metrology) and soft skills (i.e., design methodology, teamwork, schedule planning, documentation, and communication).
- c) Clicker assessment. Daily clicker assessment summarizes and highlights key points in lectures and laboratory practices. It also helps to retain new knowledge while providing teaching materials for the participants at their respective schools. Much improvement has been observed among participants after the successful implementation of the clicker assessment.

The teachers would spend the last week to prepare and present plans for curriculum integration at their schools; they would also prepare and present their research experiences and the project outcomes as posters to other research groups on campus. Several field trips would be organized for the participants to tour local manufacturing companies, material characterization facility, and the new engineering education complex at TAMU (Figs. 10 f, h).

Post program survey shows the participants' satisfaction with the training. All participants acknowledged the new soft skills that they have received (Fig. 11). When providing feedback on the newly acquired knowledge on technical hard skills, the participants agreed to the topic relevancy, workload, and training program. Figure 12 shows if the training is adequate to

implement each topic at the participant's class. The challenging level of 25 means the training provides sufficient knowledge and skills for implementation. The post survey acknowledges the training on most projects are enough for the participants to implement with the exception of the followings:

- Surface engineering module was rather too advanced to be implemented at high school level. The responsible faculty mentor will modify it for simplicity, practicality, and enhancement of the topic relevancy for the new batch in summer 2020.
- The content of CAD/CAM training module was rather simple, perhaps due to the limited time and machines for hands-on practice. We will integrate the CAD/CAM lessons with the comprehension project in the coming summer.

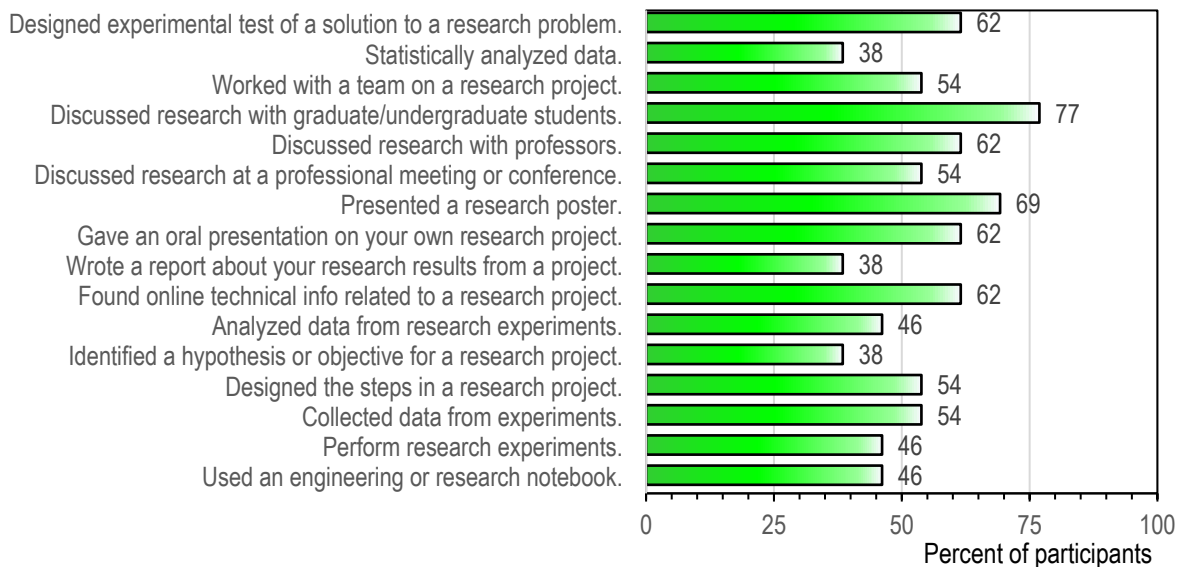


Fig. 11. Feedback on new soft skills after the training program. Summer 2019.

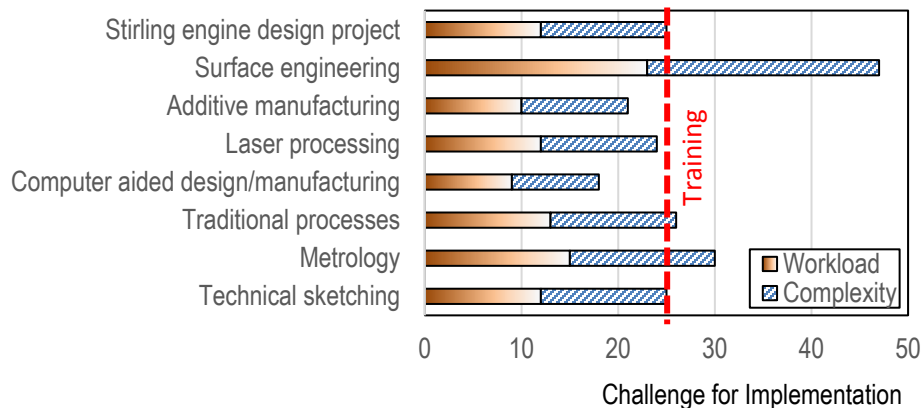


Fig. 12. Feedback on new hard skills after the training program. Summer 2019.

While the overall training impacts are being assessed, preliminary information shows the success of this RET training program:

- Gene Haas Foundation and industry generously match NSF funding to train additional teachers without significant efforts from faculty mentors and student assistance. We had

one additional teacher in summer 2019, and will plan for three additional teachers in summer 2020.

- The Harlingen high schools successfully received grant from the Texas' Jobs and Education Training (JET) program to further enhancing its technical education program.
- One teacher was tasked with heading the new Career and Technical Education (CTE) center for Bryan ISD. Support of this new CTE and our university has been approved by both institutions due to close proximity of the institutions, and similar manufacturing activities.
- Two teachers participated in two regional conferences every year to inform others of their new curriculum implementation.
- The teachers guided their students to win at numerous competitions in the regions and state. One teacher and his team won the state-level robotic competition, and was honored to be the recipient attending and presenting his work at the NSF Grantee conference last year.
- Seven technical/educational articles were published from the work of teacher participants with the faculty mentors and their graduate students.
- About 200 students attended the recent Manufacturing Day, 4 October 2019, at TAMU campus and exposed to many manufacturing-related topics. Many motivated students have expressed their desires to apply for further studies upon graduation from their high schools (Fig. 10h).

However, the remaining challenges for this program include:

- Participant Selection. Some in-service teachers (3/20) delayed the implementation of their proposed curricula. Despite the RET faculty support, the delay perhaps was due to the shift of school focus and/or lack of the teacher's determination. A better screening method and request for up-front support from school principals will be implemented for the next cycle.
- Broader impact. Many STEM applicants are yet to be involved with pre-engineering program. We will include selected in-service teachers who are involved with STEM class and have shown interest in developing pre-engineering program and robotic club at their schools.

VI. Summary and Recommendations

This three-year program aims to improve the manufacturing skills and knowledge of teachers from schools with high numbers of underrepresented groups. Highlights of the program impact include:

- The program successfully trained of 20 in-service teachers and 5 pre-service teachers in the last two summers. The participants learned the theories and practiced fundamentals of traditional manufacturing, additive manufacturing, laser machining, metrology, and surface engineering.
- The Harlingen high school obtained a state grant for technical training, and the McAllen high school expanded its robotic program after winning their state championship last year.

The 2020 summer program is delayed due to Covid-19 issue. In the summer 2021 we plan to streamline and enhance the program by:

- Revising the screening method to expand the pool of applicants while selecting motivated candidates.
- Training additional teachers with matching fund from industry and Gene Haas Foundation.
- Simplifying the surface engineering project.
- Continuing with clicker assessment and having a comprehensive project that links all lessons and laboratory exercises.

Acknowledgement

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